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# PERFORMANCE OF NOMEX® MILITARY UNIFORMS IN ATTACKS BY FLAME FIELD EXPEDIENT WEAPONS – A LITERATURE STUDY

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The purpose of this final report is to highlight on the development and design of flame resistant uniforms such as Nomex brand uniforms and whether they provide greater protection from burns than Desert Camouflage Uniforms (DCUs). Assessments on the Nomex uniforms and DCUs have been made based on the research evaluations and tests conducted by government and industry. Various types of fabrics have also been evaluated to determine which provide insulating qualities that were most appropriate for thermal protection.

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## Table of Contents

## *Purpose*

The purpose of this document is to answer the question "Will Nomex uniforms provide greater protection from burns than Desert Camouflage Uniforms (DCUs) during attacks by exploding Flame Field Expedient (FFE) weapons."

## *Background*

### Burn Protection

Research indicates that when skin temperatures are elevated above the 44°C (111.2°F) threshold, burns may occur. Higher temperatures and longer exposure times result in burns of greater depth and severity. Thermal protective uniforms are designed to insulate the wearer from heat sources, and to resist ignition, shrinkage, and rupture when exposed to flames. Flame resistant (FR) uniforms in the Defense Logistics Agency (DLA) inventory were developed based on military requirements that they provide a survivable escape time of 3 - 10 seconds during fire emergencies[5].

### FFE Threat

Exploding FFEs are unsophisticated field-made incendiary weapons. Many sizes and types of these devices exist; however, they typically consist of both an explosive charge and a thickened fuel accelerant. Upon detonation, the explosive propels burning fuel over a large area. Thickened accelerants tend to stick to all types of surfaces, to burn hot for extended times, and to resist quenching. Personnel attacked by FFEs may experience both severe burn and blast injuries. Resulting burns to the face and respiratory tract are often life-threatening.

### DCU

The currently fielded Desert Camouflage Uniform (DCU) consists of trousers, coat, and headgear conforming to MIL-C-44034D, Cloth Twill Camouflage Pattern Cotton and Nylon for Desert Uniform. It is constructed of a 7 Oz. /$yd^2$ 50% cotton and 50% polyester blend textile sewn with a polyester-based thread. DCUs are treated with both water and insect repellents. The Military Specifications pertaining to the DCU do not address any thermal protection parameters. This uniform was not designed to provide any protection from temperatures greater than those normally encountered during ambient weather conditions.

### Nomex

Nomex is the trademark name for the E. I. Du Pont de Nemours and Company (Du Pont) family of aromatic polyamide (Aramid) fibers. Nomex was developed by Du Pont in the early 1960's and commercially produced in 1967 with the cooperation of the DoD. Worldwide, more

commercial and military FR garments are made of Nomex than all other fiber types combined. These fibers have a flame resistance due to their molecular structure, which allows them to withstand temperatures up to 400°C (752°F). Instead of melting, they form a protective char when exposed to flames. Nomex also quickly self-extinguishes when removed from flame sources. Afterward, it retains much of its original strength and abrasion resistance without excessive shrinkage, which decreases the likelihood that it will break open. Nomex garments made of equivalent weight cloths have much more wear endurance than garments made of natural fiber or natural fiber blends.

## *Military Fire Resistant Uniforms and Accessories*

Nomex military uniforms are made from Du Pont's Type 455 and Type 462 Nomex III and Nomex IIIA fibers, respectively. Nomex III is a 95/5% blend of Aramid and Kevlar fibers. Nomex IIIA is a 93/5/2% blend of Aramid, Kevlar, and P-140 static dissipative fibers. The P-140 fiber has a conductive carbon black core covered in a protective polyamide sheath. The characteristics of Nomex III and Nomex IIIA cloths are shown in Table 1 Characteristics of Nomex and Cotton Fabrics in Appendix A. The primary source for Department of Defense (DoD) uniforms is the Defense Logistics Agency (DLA).

### CWU-27/P Flight Suit

The CWU-27/P Summer-weight (4.5 oz.) flight coverall is made from Nomex IIIA cloth. It is a one piece, unlined garment with a zipper front closure and side pass-throughs. It has Velcro adjusters for the waist sleeves, and legs. It includes two welt-style breast pockets, one combination cigarette pack and pencil compartment on the upper front left sleeve, two thigh pockets, a knife pocket on the left thigh, and a pocket on the right lower leg. This uniform item is available in either Tan 380 or Sage Green.

### CWU-64/P Flight Suit

The CWU-64/P (MIL-C-87230A) winter weight flight suit is made similarly, but of 7 oz. cloth. It also has a hood concealed in its collar. Commercial versions of both flight suits are available from a multitude of vendors in many color choices.

### Combat Vehicle Crewman's Coverall

The Combat Vehicle Crewman's Coverall (CVC) is made of the same cloth as the CWU-27/P; however, in this coverall, the knees and seat are reinforced, it includes zippered pockets at the waist, it has a retrieval loop and a Velcro closure at the lower end back, and it also has elastic sleeves and leg bottoms. The sleeves have been designed so that it is difficult to roll them up. It is available in the OD 106, GG-483, Tan 380, Three-Color Desert Camouflage, and Woodland Camouflage colors.

## Improved Air Crew Battle Dress Uniform

The Improved Aircrew Battle Dress Uniform (IABDU) is a two-piece camouflage flight uniform that is constructed similarly to the standard BDU; however, it is constructed of Nomex cloth. The design also includes elbow and shoulder patches, a left sleeve pocket, lower-leg pockets with zippered or Velcro fasteners, and a knife pocket on the inner left trouser leg. It is available in the Tan 380 or CG-483 Woodland Camouflage colors.

## CWU-36/P Jacket

The CWU-36/P Flyer's Summer Weight Jacket is made of fully lined 6 ounce Nomex Cloth. It has a zippered front closure, elastic wrist and waist bands, diagonal side welt pockets, a left sleeve combination cigarette and pencil pocket, and a collar with Velcro tab closure. It is available in Tan 380, OD 106, and Sage Green.

## CWU-45/P Jacket

The CWU-45/P is a heavyweight version of the Summer Weight Jacket intended for cold weather operations.

## Improved Aircrew BDU Jacket

The Aircrew BDU Jacket is of a fully lined and single breasted design with a front zipper closure covered by a protective flap. The back has a yoke and a retrieval strap opening with a Velcro closure. The left sleeve has a utility and pencil pocket and includes elbow patches. The cuffs and waistband are rib knit. The jacket is available in Tan 380, OG 106, and CG-483 Woodland Camouflage colors.

## Aramid Underpants and Undershirts

Nomex (Aramid) fiber underpants and undershirts are available for use with nomex uniform items. Both of these items are constructed in the traditional style of "long johns," and are normally used in cold climates. They also offer more thermal protection than short-sleeved undershirts and drawers.

## Aramid Cold Weather Liners

The CVC Coverall Liner is made from a quilted Aramid batting material, and is worn under the coverall to provide additional thermal insulation and protection. They are a set of upper and lower garments, which can be connected at the waist. The upper garment is of a waist-length jacket configuration with long sleeves. The trousers attach to the upper garment with buttons. The coverall can be worn with the both the upper and lower garments liner, or just the upper liner alone.

### Aramid Gloves

There are several types of FR gloves in the DLA inventory. Air Crews wear the currently fielded GS/FRP-2. The GS/FRP-2 Flight Glove is made of nomex cloth, which is covered with a leather palm, which extends through the gauntlet. These are designed with a snug fit to provide enough dexterity and tactility to allow for the operation of a vehicle. A generous portion of cloth extends beyond the wrist, which ensures that skin is not exposed between the glove and the shirt sleeve.

### Aramid Balaclavas and Hoods

The Anti-Flash Hood is made of a lightweight and breathable blend 80 percent flame resistant Rayon and 20 percent polybenzimidazole (PBI) high performance fiber. The top portion is worn snug to the head, but the bottom flares into a yoke, which is tucked into the shirt opening. It incorporates a circular face opening, which is edged in elastic webbing. The hood is only available in an off-white natural color. A heavyweight Sage Green version, which is made for the CVC is also available through DLA.

## *Tests to Evaluate Reaction of Thermal Protective Garments*

Reaction-to-fire tests are used to evaluate the fire resistance offered by protective garments. Researchers use these tests to determine the likelihood that FR garments will prevent burns to their wearers. These tests are described below.

### Limiting Oxygen Index Test

Standards: ASTM D 2863, ISO 4589

The Limiting Oxygen Index (LOI) test determines relative flammability. The 'LOI' is the minimum concentration of oxygen in a specified atmosphere required to support downward burning of a vertically mounted test specimen. The test is reproducible to an accuracy of approximately 0.5%. Results of this type of test on Nomex and cotton are provided in Appendix A.

### Vertical Flame Test

Standards: Federal Test Standard 191A Method 5903.1, ASTM D 6413

This test determines the relative flammability of textile test specimens, which are rigidly held in a metal frame. A methane burner provides an impinging flame for 12 seconds. Researchers record the char length, afterflame, and afterglow. Fabrics which have shorter char lengths and burn times are more resistant to burning and therefore tend to be better choices for FR garments. This test does not quantify how much thermal insulation the textile provides. A fabric, which does not readily ignite, may still transfer sufficient heat to cause skin burns.

When evaluated by this test, cotton and polyester/cotton blend fabrics (such as DCUs) ignite within seconds and continue to burn until the entire sample is consumed, even if the methane flame is removed. Polypropylene, polyester, and nylon fabrics melt, and then ignite. Nomex fabrics do not continue to burn once the methane burner is removed. Nomex does not melt. Nomex cloths meet MIL-C-83429B, Cloth, Plain and Basket Weave, Aramid, which requires a char length of less than 4 inches, an afterflame of less than 2 seconds, and an afterglow of less than 25 seconds. Results of this type of test on Nomex and cotton are provided in Appendix A.

## Thermal Protective Performance (TPP) Test

Standards: NFPA 1971, ISO 17492, ASTM D 4108

The Thermal Protective Performance (TPP) Test determines how much thermal insulation is provided by either a textile or a textile assembly. It may also be used to evaluate the constancy of fabric samples during heating. Two gas burners and six radiant quarts tubes are used to impose a 50/50% convective/radiant heat flux of 2 cal/cm$^2$-sec (84 kW/m$^2$) on a 4 square inch sample. A calorimeter measures the backside temperature rise. An associated data acquisition system determines how long it takes for the calorimeter to reach 44ºC, the second degree burn threshold temperature for human skin. Longer times for the calorimeter to register 44ºC indicate that the textile or textile assembly provides more protection. Results of this type of test on Nomex and cotton are provided in Appendix A.

## Lateral Ignition and Flame Spread Test

Standards: ASTM E 1317, ASTM E 1321, NFPA 264, ISO 5658

The Lateral Ignition and Flame Spread Test (LIFT) uses a gas-fired radiant panel to impose a range of heat fluxes on a sample. This test determines the minimum heat flux, which is required for ignition, how long it takes for ignition to occur, the surface temperature at ignition, and how quickly the flame spreads. After testing with LIFT, samples can be compared to ascertain which would be the better choice for FR garments.

## Outdoor Fire Pit Instrumented Manikin Testing

Standards: None – led to development of ASTM F 1930

Before testing standards were formalized, several DoD and commercial entities operated outdoor instrumented manikin test facilities. Generally, a durable manikin would be fitted with a multitude of temperature sensors. The manikin would then be suspended from a boom and moved through flames of various intensities, which emanated from a fire pit. Operators would vary the exposure time by speeding or slowing the traveling boom. The fire pit was used to create petroleum fuel fires. This type of testing has been used to subject FR clothing to a range of realistic weather-dependent fire conditions.

### Environmental Chamber Instrumented Manikin Testing

Standards: ASTM F 1930, ISO 13506

This test determines the percentage of body burn that the wearer of a FR garment would receive if he/she were subjected to flash fires of various intensities. It is similar to outdoor instrumented manikin tests; however, the type, number, and location of the temperature sensors as well as the humidity/wind conditions have been standardized. Furthermore, the heat flux, flame distribution, and flame duration are controlled. This full scale test most accurately predicts the level of protection given to users by their FR garments. Results of this type of test on Nomex and cotton are provided in Appendix A.

### Wash Cycle Testing

Standards: None – Though standards for this type of testing now exist, most Nomex uniform items were tested IAW locally developed protocols.

FR garments must be durable otherwise they may rupture during fire events. Washing a garment weakens it. In wash cycle tests, a garment is carried through a number of wash cycles, and then it is evaluated for strength and fire resistance. The goal of these tests it to correlate the protection given by FR garments with the decomposition they experience due to laundering. Once this is known, garments can be replaced before their protective qualities are nullified.

### User Wearability Testing

Standards: None

Various DoD organizations have conducted wearability tests to evaluate the relative durability of Nomex and other types of uniforms. Usually these tests involve having a large number of people wear FR uniforms in the performance of their duties for several months. The individuals involved then submit completed surveys, which describe their experiences with the clothing. This data is then analyzed for trends, which yield clues about the uniform's comfort, functionality, and durability.

## *Studies of Thermal Protection Provided by Various Military Uniforms*

Nomex clothing items have been the subject of many studies conducted by both military and commercial entities. Most of these studies involve either flammability comparison studies or wearability and wash cycle studies.

### Flammability Comparison Studies

In flammability comparison studies, several types of FR and/or non-FR garments are subjected to a battery of reaction-to-fire tests. The results of these tests are then analyzed to determine which of the subject items would be best suited for a given military application.

## Comparative Wearability and Wash Cycle Studies

In these studies, several types of uniforms are tested with a combination of wash cycle tests plus user wearability tests, reaction-to-fire tests, and/or tests to determine the textile strength. The goal of these studies is to determine which uniform would be most appropriate for a given application. These studies may resemble this format: 25 each of uniform types A, B, C, and D will be washed 0, 5, 10, 25, 50, and 100 times. After washing, the uniforms will undergo ASTM F 1930 Manikin Testing. The data will then be analyzed to determine which would be best suited for a 6-month deployment.

## *Synopsis of Selected Government-Sponsored FR Garment Studies*

### 1960s Testing

**Report Title: Laboratory Shrinkage Evaluation of Nomex Summer Flight Suits**

Date of Publication: April 1967

Organization Performing the Study: Naval Air Engineering Center

Summary of Test Methodology: Wash Cycle Study – Nomex flight suits were washed in 140°F water, then previously marked dimensions were measured to determine if excessive shrinkage had occurred.

Key Findings: Nomex fabric does not shrink excessively when laundered.

**Report Title: Special Safety Study. Testing 'Nomex' Material as Heat Resistant Clothing for Industrial Application**

Date of Publication: July 1967

Organization Performing the Study: Longhorn Army Ammunition Plant

Summary of Test Methodology: Flammability Comparison Study using Instrumented Manikin Tests – Manikins wearing light and heavyweight Nomex coveralls, fire-retarded cotton (FRT) coveralls, and aluminized knee-length fiberglass coats over various combinations of Nomex or cotton underwear were exposed to fireballs lasting up to fourteen seconds. Researchers then determined which combination of protective clothing was the most appropriate for workers in an Army ammunition plant.

Key Findings: Nomex coveralls provided the greatest protection when they were worn with underwear because the air trapped between layers of clothing insulated the wearer. Heavyweight Nomex coveralls, consisting of 7 oz. /syd. gave more insulation than lightweight Nomex coveralls of 5 oz. /syd. This study referenced industrial wearability tests, which showed that Nomex garments will last approximately six times as long as FRT cotton garments.

Note: Many serviceable Vietnam-era Nomex military garments are currently available.

**Report Title: Camouflage Printing of Nomex Summer Flying Coveralls**

Date of Publication: September 1966

Organization Performing the Study: Naval Air Development Center

Summary of Test Methodology: Comparative Flammability and Wearability Study

Key Findings: The resin-bonded pigment system used to print the camouflage pattern on the Nomex staple did not significantly alter its flame-resistant characteristics.

## 1970s Testing

**Report Title: The Protective Characteristics of PBI and Nomex Coveralls in JP-4 Fuel Fires**

Date of Publication: April 1972

Organization Performing the Study: Air Force Materials Laboratory

Summary of Test Methodology: Comparative Flammability and Wearability Study – Over 1,000 Nomex and polybenzimidazole (PBI) flight suits were used to conduct user wear tests, vertical flame tests, and outdoor fire pit instrumented manikin tests. The objective of this study was to determine whether PBI or Nomex flight suits would provide greater thermal protection to pilots escaping from simulated aircraft crash fires.

Key Findings: PBI flight suits provide greater protection from burns than Nomex flight suits. PBI fabrics are more comfortable to wear than Nomex fabrics. Nomex is more abrasion-resistant than PBI. Both PBI and Nomex fabrics will greatly outlast cotton fabrics. Fabric thickness, porosity, density, and weave impact its ability to insulate skin from heat sources; of these, density is the most critical factor. Flight suits made from two layers provided the most protection. Petroleum pool fires yield highly variable thermal environments. The percent of body area damaged is closely related to the amount of energy absorbed during a thermal exposure. Extremities receive the greatest burn damage when exposed to petroleum pool fires.

**Report Title: Evaluation of Four Thermally Protective Fabrics Using the USAARL Bioassay Method**

Date of Publication: June 1978

Organization Performing the Study: Army Aeromedical Research Laboratory

Summary of Test Methodology: Burn Comparison Study using Anesthetized Pigs – This study determined which of four fabrics was most effective in mitigating porcine burns. Pig skin,

covered by one of two types of Nomex fabrics, one type of PBI fabric, an experimental fabric, or no fabric was exposed to a JP-4 burner. Tests were run with and without air gaps and with and without the addition of cotton undershirts. Doctors evaluated the resulting burns both immediately after the exposure and after 24 hours had elapsed. After the second evaluation, tissue biopsies were taken for further analysis.

Key Findings: Human and porcine skins respond similarly when exposed to high temperatures. The configuration most effective in mitigating burns was the double fabric layer with air gaps. Nomex, PBI, and the experimental fabric, when tested with undergarments and gaps, lessened burns to nearly the same degree.

**Report Title: Heat Resistant and Nonflammable Materials**

Date of Publication: April 1976

Organization Performing the Study: Air Force Materials Laboratory

Summary of Test Methodology: Comparative Flammability Study using various bench and full scale reaction-to-fire test apparatus – The flame response of cotton, nylon, polyester, Kynol, Durette, Nomex, and other fibers and fabrics was observed.

Key Findings: FR garments must remain flexible and intact in order to protect wearers, who are escaping from fires. Nomex requires a much higher heat flux for ignition than cotton. Nomex retains a greater portion of its full strength for a longer period of time under heating than cotton. Polyester and nylon quickly lose strength and then melt when exposed to heat fluxes typical of vehicle crash fires.

**Report Title: Analysis of the Thermal Response of Protective Fabrics**

Date of Publication: January 1973

Organization Performing the Study: Air Force Materials Laboratory

Summary of Test Methodology: Comparative Flammability Study – Various bench scale reaction-to-fire test apparatus and instrumented manikins were used to gather flammability data on Nomex, PBI, and Stabilized PBI constructs. This data was then used to develop a computer model. The model was able to reasonably predict the extent of burn damage that wearer's would receive when exposed to actual fires.

Key Findings: The air that exists between layers of clothing contributes greatly to the ability of an ensemble to insulate its wearer from exposure to elevated temperatures. Heavyweight fabrics provide considerably more thermal protection than lightweight fabrics of the same material. Moist materials provide greater protection than dry materials because they delay the temperature rise, which reduces the heat transfer into the wearer's skin. Nomex ignites at approximately 550°C (1,022°F).

**Report Title: Nonflammable PBI Fabrics for Prototype Air Force Flight Suits**

Date of Publication: November 1970
Organization Performing the Study: Air Force Materials Laboratory

Summary of Test Methodology: Flammability Comparison Study using Instrumented Manikin Tests – Single and double layer flight suits constructed of cotton, Nomex, and PBI were evaluated for relative flammability using instrumented manikins in an outdoor fire pit facility.

Key Findings: The percentage of body burn for manikins wearing Nomex flight suits was approximately half of that experienced by manikins wearing cotton flight suits. Wearing double layer Nomex flight suits halved the burn damage again. Manikins wearing Nomex flight suits over Nomex long underwear did not receive any burn injuries.

## 1980s Testing

**Report Title: Evaluating the Thermal Protective Insulation Properties of Advanced Heat-Resistant Fabrics**

Date of Publication: April 1987

Organization Performing the Study: Department of Textile Engineering and Science, North Carolina State University (an Air Force Materials Laboratory contractor)

Summary of Test Methodology: Comparative Flammability Study – The Thermal Protective Performance (TPP) apparatus was used to evaluate the insulating qualities of woven, knit, and felt weaves of PBI, PBI/Kevlar, Kevlar, Nomex, PBI/Rayon, and PBI/Nomex of various fabric weights.

Key Findings: Moisture in the fabric contributes to increased thermal protection. Non-woven fabrics provide better protection than woven fabrics.

**Report Title: Fire Tests of Advanced Aramid Blends and Treatments**

Date of Publication: December 1987

Organization Performing the Study: Naval Air Development Center

Summary of Test Methodology: Comparative Flammability Study using instrumented manikins in an outdoor fire pit facility were exposed to JP-4 pool fires for three or four seconds with four types of protective garments: Nomex Sage green (solution-died) flight, Nomex tan flight, 20% PBI, 80% Nomex flight, and Nomex Camouflage Battle Dress Uniforms (BDU) . No further details were reported on the weight or construction of the garments.

Key Findings: The Nomex BDU resulted in the smallest percentage of body burn because its construction was the most shrink-resistant. The type of dye and the manner in which it is applied can affect the burn characteristics of uniform items.

**Report Title: The New Navy Flyer's Fire-Resistant Blue Coverall**

Date of Publication: August 1984

Organization Performing the Study: Naval Air Systems Command

Summary of Test Methodology: Flammability Study using instrumented manikins in an outdoor fire pit facility – Blue (piece-died) Nomex cloth was used to construct flight suits similar to the Air Force's CWU-27/P uniform. These were then evaluated for their flammability characteristics.

Key Findings: Some dyes use a flammable carrier. This carrier is harder to remove from piece-died textiles, which makes them more flammable than solution-died garments. In this series of manikin tests, the dye burned out of the Nomex. Some commercially-available Nomex garments, that do not meet MILSPECS, will be more flammable than those that do. Uniform items worn with the Nomex coverall will increase the thermal protection it provides.

**Report Title: US Navy Protective Clothing Program**

Date of Publication: July 1984

Organization Performing the Study: Naval Air Systems Command

Summary of Test Methodology: Comparative Flammability and Wash Cycle Study – FRT cotton and Nomex uniforms were evaluated with Vertical Flame and Instrumented Manikin tests. Items were tested new and after undergoing 25 and 50 wash cycles.

Key Findings: The burn characteristics of Nomex coveralls remain essentially the same regardless of whether they were new, or had been washed up to 50 times.

## 1990s Testing

**Report Title: Reduction and Mitigation of Thermal Injuries; What Can be Done**

Date of Publication: January 1996

Organization Performing the Study: US Army Aeromedical Research Laboratory

Summary of Test Methodology: Document and Statistical Evaluation – Statistics were acquired from the collections of the US Army Safety Center and elsewhere, which related to post-crash fires and thermal injuries associated with aviation, armor, and refueling operations. These were evaluated to discovery plausible explanations for burn injury trends.

Key Findings: The Army provided aircrews with Nomex flight apparel in 1968. Armor crews received protective Nomex clothing in 1970. There was an immediate and dramatic decrease in incidences of thermal injuries following these actions. Wearing nylon fabrics with Nomex negates the protection Nomex would normally provide during a fire because the nylon melts and sticks to and burns the skin when exposed to high temperatures. Footwear containing nylon may shrink and cause Achilles tendon injuries during fires. Units should ensure that leather footwear is worn with FR garments. Servicemen wearing Nomex garments without proper undergarments may receive serious burns during fire emergencies. Army Regulation 95-1, Aviation Flight Requirements, requires cotton or wool undergarments with Nomex garments. This report showed that maximum protection is provided with this combination. PPE is effective when used as designed.

## 2000s Testing

**Report Title: Fire Blankets for Munition Protection: Flame and Heat Blocking Properties of Advanced Materials**

Date of Publication: February 2001

Organization Performing the Study: Army Research Laboratory

Summary of Test Methodology: Comparative Flammability Study – Twenty-seven types of fabrics, including some containing Nomex fibers, were evaluated to determine which provided insulating qualities that were most appropriate for the thermal protection of stored munitions. Bench-scale tests were used to evaluate how heat flowed through the prototype blankets.

Key Findings: During accidents or combat situations, stored munitions may be exposed to temperatures measuring thousands of degrees. Insulating blankets are used to prevent catastrophic explosions under these circumstances. Resistance to heat and flame penetration is enhanced when blankets use alternating layers of organic and inorganic fabrics. This combination may be used to develop FR garments for extreme high-temperature applications.

## *Conclusions*

- The DCU is made of a cotton/polyester blended fabric. In all comparative flammability studies, this type of fabric experienced thermal failure, resulting in burns, well before any Nomex fabric used in similarly constructed garments. (See Synopsis of Selected Government-Sponsored FR Garment Studies: Heat Resistant and Nonflammable Materials, Nonflammable PBI Fabrics for Prototype Air Force Flight Suits, and Reduction and Mitigation of Thermal Injuries; What Can be Done)
- Nomex fabric is much more durable than the DCU fabric. (See Synopsis of Selected Government-Sponsored FR Garment Studies: Special Safety Study. Testing 'Nomex' Material as Heat Resistant Clothing for Industrial Application, The Protective Characteristics of PBI and Nomex Coveralls in JP-4 Fuel Fires, and US Navy Protective Clothing Program) Nomex outlasted cotton by a factor of at least four to one in all wash cycle and wearability tests.
- Nomex uniforms will provide better protection than the DCU during exploding FFE attacks because it will resist more intense heat and last far longer. Typical results of reaction-to-fire tests are shown in table 1 in Appendix A, Characteristics of Nomex and Cotton Fabrics. Nomex provides the best combination of flame resistance, insulation, comfort, durability, versatility, and cost-effectiveness.
- In accordance with the study Fire Test of Advanced Aramid Blends and Treatments, Nomex BDU uniforms will shrink less during fire events than Nomex flight suit uniforms.

Procedures to ensure that Nomex garments perform up to their potential:

1. Wear natural fiber undergarments such as cotton or wool. FR undergarments provide even better protection. Common synthetic fabric undergarments containing a blend of nylon, polyester, or polypropylene will melt at relatively low temperatures and severely burn individuals who are escaping fire emergencies. This conclusion was clearly demonstrated in the report *Reduction and Mitigation of Thermal Injuries; What Can be Done* by Voisine and Albano.

2. Wear layers. Air is an excellent insulator. Air between layers of clothing greatly delays the transmission of heat and plays a major role in insulating the wearer's skin from the heat of any impinging flames.

3. Use only garments, which meet MILSPECS. Some inexpensive garments sold as FR-rated have been found to be constructed with flammable dyes and threads, which melt in the presence of elevated temperatures. Fasteners, such as zippers and buttons must withstand temperatures on par with the garment's fabric in order to prevent premature thermal failure.

4. Be wary of contaminants. Most insect repellants, petroleum products, and even body oils degrade the ability of FR garments to withstand flames and high temperatures. Wash garments in accordance with label instructions.

5. Limit exposure times to extremely high temperatures when possible. Nomex uniforms are flame resistant, not flame proof. All military FR garments are designed to provide a few SECONDS (normally 3 to 10 seconds) of escape time during fire emergencies before thermal injuries occur. All garments of all types will eventually fail during a large and intense fire.

## *Recommendations*

Issue Nomex BDU uniforms (Desert Tan 380 coat & trousers, flight gloves, anti-flash balaclava, cotton undershirt, cotton underwear, and leather boots) to servicemen who will potentially be exposed to FFE weapons.

Include maintenance of Nomex uniforms as part of the overall unit Operational Risk Management (ORM) strategy.

Mitigate facial burns with balaclavas, goggles, face shields, or other means (chemical protective masks may be an alternative, but this option has not been evaluated).

Review DoD publications, which address FFE to better understand the fire hazard. These publications include: FM 3-11, Multi-Service Tactics Techniques and Procedures for Nuclear Biological and Chemical Defense Operations; FM 3-100, NBC Defense Chemical Warfare Smoke and Flame Operations; and FM 3-7, the NBC Field Handbook, among others.

Equip and train personnel to respond to FFE Attacks. During an FFE attack, every second is critical. The usual FFE attack reaction includes a period of initial chaos. Training can decrease the duration of this reaction and lead to safer and more effective unit ground operations.

Conduct research to characterize flame fuels. There is a gap in the general and scientific understanding of the properties and behavior of flame fuels, which are the heart of every FFE weapon. Before more effective strategies can be devised to nullify these weapons, we have to understand how they work.

Conduct Research to characterize FFE attacks on personnel and vehicles. What is the effective range of the available assortment of FFE weapons? What effects can be expected once they are detonated? What is the best way to prevent individuals, equipment, and vehicles from succumbing to these effects?

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## *Appendix A: Characteristics of Nomex and Cotton Fabrics*

**Table 1 Characteristics of Nomex and Cotton Fabrics**

| | **Nomex III and IIIA** | | | **Cotton** |
|---|---|---|---|---|
| Tested Parameter | 4.5 oz/syd (0.153 kg/$m^{2)}$ | 6 oz/syd (0.203 kg/m2) | 7 oz/syd (0.255 kg/m2) | MIL-C-43468 6 oz/syd (0.203 kg/m2) |
| Water Absorption (%) | 8.3 | 8.3 | 8.3 | 24-27 |
| Ultimate Tensile Strength [ksi (Mpa)] | 45 (310) | 45 (310) | 45 (310) | 44 (303) |
| Elongation at Break (%) | 21 | 21 | 21 | 3-9.5% |
| Air Permeability (cfm/$ft^2$) | 239 | 83 | 56 | 13 |
| Vertical Flame | | | | |
| Char Length (in.) | 3.3 | 3.1 | N/A | 12 |
| Afterflame (s) | 0 | 0 | N/A | 36 |
| ASTM F 1930 Instrumented Manikin ( Predicted % body burn) | | | | |
| 3s at 2 cal/$cm^2$s | 38 | 29 | 19.3 | unavailable |
| 4s at 2 cal/$cm^2$s | 51.7 | 44.3 | 36.7 | unavailable |
| 5s at 2 cal/$cm^2$s | N/A | 58 | 53.3 | unavailable |
| ASTM D 4108 TPP Rating | 11.8 | 13.3 | 15.3 | N/A - Ignites |
| Ignition Temperature °C (°F) | >500 (932) | >500 (932) | >500 (932) | 350 (662) |
| Limiting Oxygen Index % | 29 - 30 | 29 - 30 | 29 - 30 | 18.4 |

## *Appendix B: Nomex Uniform Specifications, National Stock Numbers, and Prices*

### Table 2, Nomex Uniform Specifications and National Stock Numbers

| Item Name | MILSPEC | Size | NSN | Est. Cost |
|---|---|---|---|---|
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Small Short | 8415-01-498-5107 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Small Regular | 8415-01-498-5119 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Small Long | 8415-01-498-5123 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Small Short | 8415-01-498-5125 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Small Regular | 8415-01-498-5127 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Small Long | 8415-01-498-5131 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Medium Short | 8415-01-498-5133 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Medium Regular | 8415-01-498-5134 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Medium Long | 8415-01-498-5135 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Large Short | 8415-01-498-5137 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Large Regular | 8415-01-498-5140 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | Large Long | 8415-01-498-5143 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Large Short | 8415-01-498-5144 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Large Regular | 8415-01-498-5147 | $90.00 |
| Air Crew BDU Coat (Nomex) | MIL-C-44371 | X Large Long | 8415-01-498-5149 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Small Short | 8415-01-498-5186 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Small Regular | 8415-01-498-5188 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Small Long | 8415-01-498-5189 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Small Short | 8415-01-498-5190 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Small Regular | 8415-01-498-5192 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Small Long | 8415-01-498-5193 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Medium Short | 8415-01-498-5194 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Medium Regular | 8415-01-498-5196 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Medium Long | 8415-01-498-5195 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Large Short | 8415-01-498-5200 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Large Regular | 8415-01-498-5197 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | Large Long | 8415-01-498-5199 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Large Short | 8415-01-498-5201 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Large Regular | 8415-01-498-5202 | $90.00 |
| Air Crew BDU Trousers (Nomex) | MIL-T-44372 | X Large Long | 8415-01-498-5204 | $90.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 5 | 8415-01-461-4920 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 6 | 8415-01-461-4922 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 7 | 8415-01-461-4924 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 8 | 8415-01-461-4932 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 9 | 8415-01-461-4934 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 10 | 8415-01-461-4940 | $25.00 |

## Table 2, Nomex Uniform Specifications and National Stock Numbers (Continued)

| Item Name | MILSPEC | Size | NSN | Est. Cost |
|---|---|---|---|---|
| Flyer's Gloves (Nomex) | MIL-81188 | 11 | 8415-01-461-4942 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 4 | 8415-01-461-8688 | $25.00 |
| Flyer's Gloves (Nomex) | MIL-81188 | 12 | 8415-01-461-8690 | $25.00 |
| Flyer's Long Undershirt (Nomex) | MIL-D-85040 | Small | 8415-00-485-6547 | $23.26 |
| Flyer's Long Undershirt (Nomex) | MIL-D-85040 | Medium | 8415-00-485-6548 | $23.26 |
| Flyer's Long Undershirt (Nomex) | MIL-D-85040 | Large | 8415-00-485-6680 | $23.26 |
| Flyer's Long Undershirt (Nomex) | MIL-D-85040 | X Large | 8415-00-485-6681 | $23.26 |
| Flyer's Long Undershirt (Nomex) | MIL-D-85040 | X Small | 8415-00-043-8375 | $23.26 |
| Flyer's Long Drawers (Nomex) | MIL-D-85040 | Small | 8415-00-467-4075 | $29.22 |
| Flyer's Long Drawers (Nomex) | MIL-D-85040 | Medium | 8415-00-467-4076 | $29.22 |
| Flyer's Long Drawers (Nomex) | MIL-D-85040 | Large | 8415-00-467-4078 | $29.22 |
| Flyer's Long Drawers (Nomex) | MIL-D-85040 | X Large | 8415-00-467-4100 | $29.22 |
| Flyer's Long Drawers (Nomex) | MIL-D-85040 | S Small | 8415-01-043-4036 | $29.22 |
| Anti-Flash Balaclava (Nomex) | MIL-H-44265 | Fits All | 8415-00-111-1159 | $35.00 |